Polars – multisite emission – multiwavelength observation

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Abstract. We review the main observational characteristics of AM Herculis stars (polars) at X-ray, EUV, UV, IR and optical wavelengths. Particular emphasis is given to multi-epoch, multi-wavelength observations of the eclipsing polar HU Aqr (RX J2107.9-0518).

In AM Herculis stars the broad-band spectral energy distribution from X-rays to the IR is governed by only very small structures: the hot accretion regions on the footpoints af accreting field lines. The most extended structures in the binary systems on the other hand, the mass-donating secondary stars and the accretion streams, distinctly appear only as Doppler-shifted emission or absorption lines. They can best be studied by investigating selected narrow spectral features in the optical, ultraviolet or the near infrared.

In this contribution both aspects will be highlighted, the structure of the accretion regions as inferred from multi-wavelength observations with low or no spectral resolution, as well as the structure of the secondary stars and the accretion streams as inferred from high-resolution spectral observations and Doppler mapping.

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1. Introduction

The broad-band spectral energy distribution of polars is governed by the processes in the small accretion regions on the footpoints of field lines, which channels the originally free-falling accretion stream down to the white dwarf. The release of gravitational energy is manifested primarily as bremsstrahlung at hard X-rays, quasi-blackbody radiation, which is prominent at EUV/soft X-ray wavelengths, and as cyclotron radiation, which is detected from the IR to the near-UV regime. Details about the relevant processes acting in the accretion region and the influence of the main parameters: the specific mass flow rate $\dot{m}$ (in g $\mathrm{cm}^{-2}\ \mathrm{s}^{-1}$), the magnetic field strength B and the mass of the white dwarf $M_{\rm wd}$, plus compilations of the observational data related to those (X-ray spectra, low-resolution optical spectra) have been given in recent reviews by e.g. Beuermann (1997), Beuermann & Burwitz (1995) and Schwope (1996). In the present paper we concentrate on the shape of light curves mainly in the X-ray region.

A different perspective of these systems is possible when viewed through ultraviolet "glasses", which reveal both the heated and unheated parts of the photosphere of the white dwarf plus reprocessed stream emission. Although observations in the ultraviolet have been performed for decades now using IUE, the data quality has improved with the advent of HST observation of polars. We describe here some preliminary results of low spectral resolution UV observations, with full phase-coverage of the eclipsing polar HU Aqr.

The existence of accretion streams in polars is a well-established observational fact. It derives e.g. from the broad emission lines in the optical/IR/UV with high radial velocities (up to $\sim$2000 km s^{-1}) varying quasi-sinusoidally, or the absorption dips seen preferentially in the X-ray light curves or, more indirectly, from the existence of hot plasma in small regions at the white dwarf magnetic poles. However, more direct information about the size of the streams and the distribution of (luminous) matter in the magnetosphere, has only been revealed recently by Doppler imaging of a few systems (Diaz & Steiner 1994, Shafter et al. 1995, Schwope et al. 1997). Methods which allow us to infer the distribution of luminous matter in the magnetosphere are ideal complements to those which allow the study of distributions of 'dark' (i.e. photoabsorbing) matter, which shape the EUV/X-ray light curves. We discuss here two examples.

Finally, the donor stars are addressed briefly. We show an example of trailed spectra of photospheric absorption lines. The Doppler image shows a "half-star" (i.e. just one hemisphere) only, demonstrating the large effects of X-ray illumination on the photospheric structure of the secondary star.

Preliminary results of a broad multi-wavelength, multi-epoch observational campaign of the eclipsing polar HU Aqr (RX J2107-0518, Hakala et al. 1993, Schwope et al. 1993) provides the backbone of this paper. Data of similar systems will be shown and discussed at appropriate places. A full analysis of the data will appear in a series of papers in the near future.

2. ROSAT and EUVE monitoring of HU Aqr

In Fig. 1 we show results of a 37 ksec observation of HU Aqr with the PSPC onboard ROSAT, when the system was in a high accretion state. ROSAT X-ray

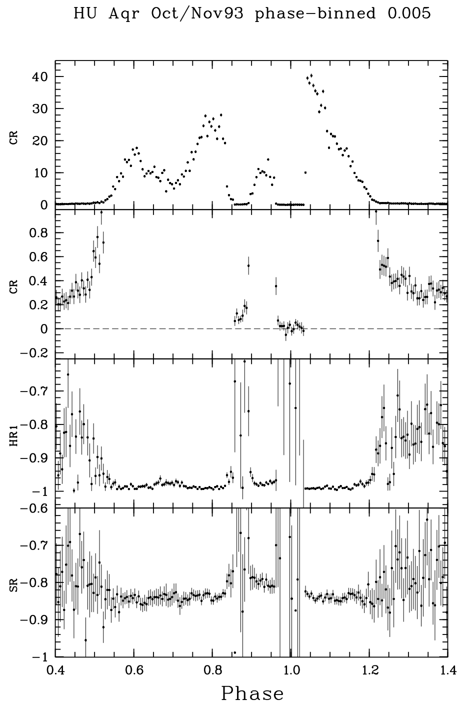

Figure 1. ROSAT PSPC X-ray light curve of HU Aqr obtained in a high accretion state in October/November 1993. Shown are from top to bottom the phase-averaged light curve in the total ROSAT band (enlarged scale in second panel), the hardness ratio and softness ratio as defined in the text

spectra of polars usually show two components: a soft component, S, below 0.5 keV and a hard bremsstrahlung component, H, above 0.5 keV. The hardness ratio HR1, defined as $(H-S)/(H+S)$, balances both components with respect to each other. The softness ratio SR is defined in an equivalent way by defining two subchannels $S1$ and $S2$ in the soft band S. HR1 and SR are also shown in Fig. 1.

The X-ray light curve of Fig. 1 shows several distinct features which will be discussed in the following paragraphs. We mention: (1) the existence of bright and faint phases alternating with the orbital period due to the specific location of the one main accretion region on the synchronously rotating white dwarf, (2) an eclipse by the secondary star centered on phase $\phi = 0.0$, (3) a pre-eclipse dip between $\phi = 0.85$ and 0.90 caused by the intervening magnetically trapped part of the accretion stream, (4) accretion flares during the X-ray bright phase caused by the impact of overdense (denser than the average) clumps of matter (not so obvious from the phase-averaged representation of Fig. 1, but better visible in some panels of Fig. 2a, the phase-averaged ROSAT HRI light curves), (5) a broad flux depression between phase $\phi = 0.60$ and 0.77 and (6) the clear detection of X-rays during the nominal faint phase, when the accretion spot is out of view. In addition, Sohl et al. (1995) report the 3σ detection of HU Aqr during eclipse phase (using the same data), which they assign to the corona of the secondary star, the first such detection in an AM Herculis star.

Faint phase X-ray emission was reported also for other self-eclipsing systems as e.g. VV Pup (Schwope et al. 1995a) and QS Tel (Schwope et al. 1995b).

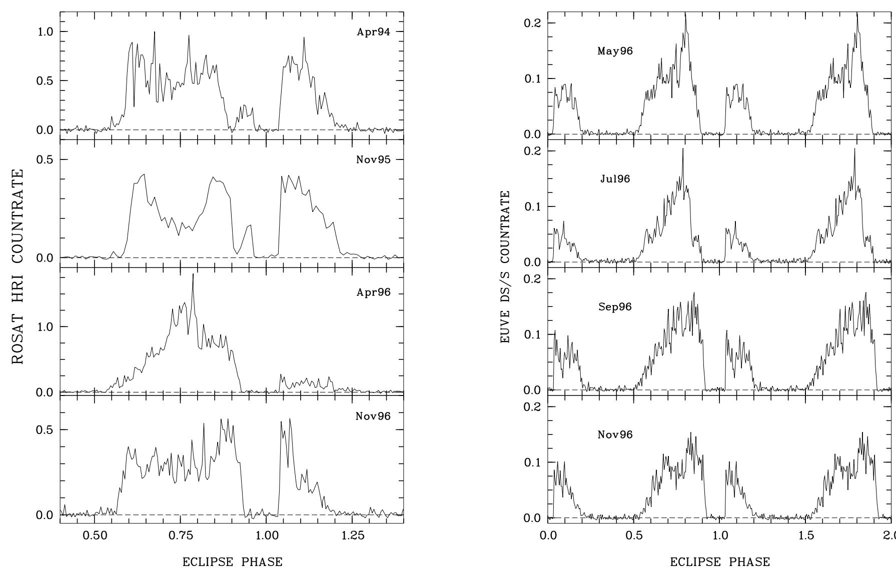

Figure 2. X-ray and EUVE light curves of HU Aqr obtained in states of reduced accretion (epochs of observation are labelled in the individual panels). Typical observation time with the HRI was 20 ksec, with EUVE 90 ksec. All data where phase-folded and averaged using the preliminary ephemeris given by Schwope et al. (1997).

Since both these systems are well-known two-pole accretors, from the detection of cyclotron lines from both poles, faint-phase X-rays were assigned to these secondary poles. In these two systems, as well as in HU Aqr, the faint-phase X-ray emission is significantly harder than the softer bright-phase emission. HU Aqr has not shown signs of a second active pole, like circular polarization or cyclotron humps. Unless the magnetic field strength is in some sense unusual (high or low), which would make cyclotron radiation non-detectable in the optical or the ultraviolet, a different explanation has to be found for the faint-phase X-ray emission in HU Aqr (which then may also be relevant for the two stars mentioned). Obvious candidates are scattered X-rays from either the stream or the secondary star. Since stream emission should be detectable also during the first few minutes of the eclipse (unless these X-rays are blocked by the accretion curtain, see below), scattered X-rays from the secondary seems to be the more likely choice.

Broad flux depressions as that of Fig. 1 ($\phi = 0.60 - 0.77$) are seen in several other systems, most pronounced in the EUVE light curve of UZ For (Warren et al. 1995), in several respects a twin to the PSPC light curve of HU Aqr. The hardness ratio HR1 increases slightly at that phase, indicating that absorption takes place. This helps to understand these depressions as caused by absorption (instead of missing emission). The huge width of the dip requires the absorbing region to be located in the very vicinity of the emission source. It's explanation

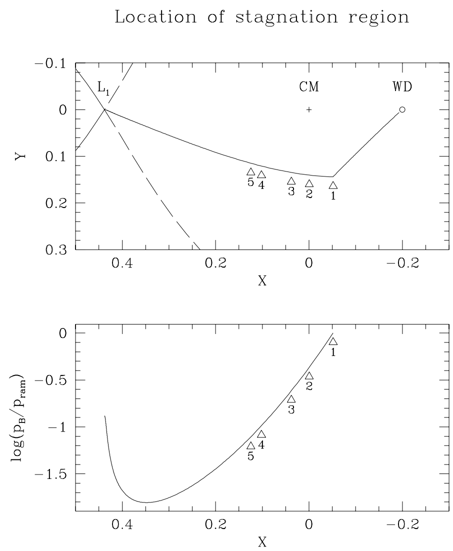

Figure 3. Model computations for the accretion stream in HU Aqr. In the upper panel a sketch of the stream and binary geometry is shown. The mass-donating companion star is to the left, the accretion stream starts at L_1. Initially it follows a ballistic trajectory, later it is re-directed by the magnetic field. Triangles mark the location of the stagnation or coupling region as measured from dip-phases at different occasions (1 – Oct 1993 … 5 – Nov96). In the lower panel the ratio between magnetic and ram pressure along the ballistic stream is shown. The computations assume constant cross section $\rho v = \dot{m} = const$ along the stream.

requires a certain temperature and geometric structure of the accretion region as well as a specific viewing geometry. Sirk & Howell (1997) have developed a numerical model and applied it to the EUVE light curves of several polars. However, such structures are obviously non-stationary. A look on the ROSAT HRI light curves of HU Aqr obtained at several epochs during recent years (Fig. 2a) shows the broad dip to be clearly present only again in Nov95, whereas a flux maximum is observed at the same phase half a year later (Apr96). At two other occasions (Apr94, Nov96) the light curve is roughly box-shaped and dominated by flares. These latter examples are quite reasonably reflected by the Hameury & King (1988) 'blobby accretion model' with no additional absorption. This model was originally developed in order to explain the anomalous state of AM Her itself.

Of particular interest is the variability of the pre-eclipse dip. Since HU Aqr is a high inclination system, $i \simeq 85°$, its phase and width are good tracers of the location and extent of the coupling region, where the initially free-falling stream is redirected. The different X-ray observations show clearly that this region is continously moving towards L_1 (the dip approaches the eclipse). During 1993–1995 the dip and the eclipse appeared as separate structures, while at later epochs both features are merged. Even at the early dates the X-ray flux between dip and eclipse was reduced to about 1/3 of the post-eclipse flux, which indicates the presence of an accretion curtain built by matter tugged from the whole ballistic stream between L_1 and the coupling region, where finally the bulk of matter is threaded. The EUVE light curves (Fig. 2b) show the same trend of dip motion on a time scale as short as two months.

We have modelled the stream with a single-particle code. It is assumed that the stream follows a free-fall trajectory as long as the ram pressure $p_{\rm ram} \propto \rho v^2 = v\dot{m}$ of the plasma is larger than the magnetic pressure $p_B \propto B^2$. The latter is computed assuming a dipolar field geometry with polar field strength $B = 37$ MG and appropriate orientation in order to reflect the location of the accretion

spot on the white dwarf in the high accretion state (azimuth derived from the center of the bright phase, co-latitude derived from the motion of cyclotron harmonics). Results of this calculation are shown in Fig. 3. This simple model gives surprisingly good agreement with the observations for the high state (epoch '1'). The magnetic pressure equals the ram pressure at an azimuth of about 45°, as observed. A pronounced decrease of the ram pressure by a factor of $\sim$10 is required in the framework of this model in order to shift the coupling point from '1' to '5'. The reduced velocity at '5' may account for a factor $\sim$2, the remaining factor 5 requires an explanation in terms of reduction of $\dot{m}$ (hence, of $\dot{M}$, the total mass flow rate in g s^{-1}). Indeed, a large decrease of the X-ray flux has taken place between epoch '1' (PSPC) and epochs '2–5' (HRI). The large reduction in count rate can be accounted for only partially by the reduced sensitivity of the HRI with respect to the PSPC, the conversion factor for a soft source as HU Aqr is about 5.5, hence there is a real decrease of X-ray flux by a factor of $\sim$5. Interestingly, there is no obvious continous further decrease of the HRI countrate between epochs '2' and '5'. This means that either our simple picture of stream-field interaction is incomplete or that the HRI-countrate cannot be used as unique tracer of $\dot{M}$, because of its lack of energy resolution. Such data may strongly be affected by absorption, or alternatively a significant part of the X-ray flux might be shifted out of the observation window due to temperature changes.

Although the azimuth of the coupling region is shifted by more than 20°, no corresponding shift of > 0.05 phase units of the bright phase center with respect to eclipse center is observed. This might be a hint to a complicated field structure in the vicinity of the white dwarf surface, where higher multipoles might become important.

3. Accretion mode changes in BL Hyi

Another striking case for large variations in the accretion geometry is BL Hyi. It was monitored already in the EXOSAT era by Beuermann & Schwope (1989) and at that time mostly showed a simple, i.e. single humped, light curve, suggesting that only one pole (the 'southern' pole, below the orbital plane) was active. However, occasional soft flares in the nominal faint phase were suggestive of a second active region. In the 1980's and during the early 1990's BL Hyi was accreting for most times at low rates. In the meantime (since $\sim$1993) the system has returned to its active state similar to that at discovery some 15 years ago. These changes have dramatically influenced the shape of the X-ray light curve, for which we show the two most recent examples in Fig. 4, together with phase-resolved photoelectric polarimetry obtained quasi-simultaneously in 1996. A hump indicating the start of the nominal bright phase can still be recognized in 1995. However, it has not survived the ongoing changes in the accretion geometry, since the 1996 phase-folded light curve is almost flat, with strong flares superimposed. This is contrary to what is seen in the optical, where the photometry still reveals a pronounced hump. Only the polarimetry reveals clearly that a second pole is active by the detection of highly polarized light in the nominal faint phase with opposite sign to the bright phase.

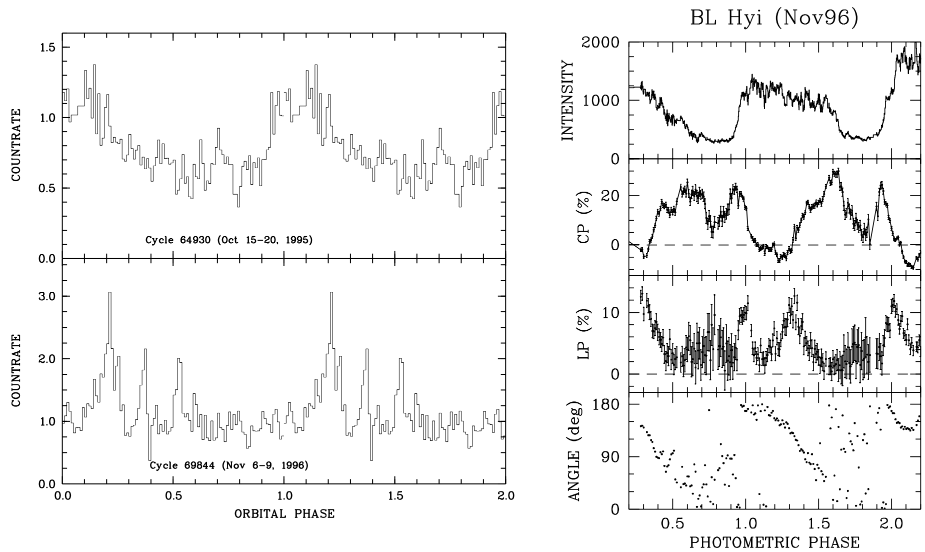

Figure 4. ROSAT X-ray (left) and optical photometric/polarimetric light curves (right) of BL Hyi obtained during high accretion states in 1995 and 1996. The 1996 data were taken quasi-simultaneously.

The accretion geometry and the field topology of BL Hyi are still a mystery. Cropper (1987) and Piirola et al. (1987) favour a high inclination as large as 75°, wheras Schwope & Beuermann (1989) argue for a low inclination of ∼35°. Ferrario at al. (1996) find a field strength of 23 MG in the accretion plasma, Schwope et al. (1995) deduce a low value of 12 MG and propose a field configuration with strong multipole components. In summary, BL Hyi is after all these years a puzzling system and observers need to sharpen their tools in order to uncover the basic parameters of this sytem, for example one may think of Doppler imaging of the accretion stream and/or the secondary star.

4. Multiwavelength photometry of HU Aqr

The large changes of accretion modes which are observed in several well-studied polars underline the importance of near-simultaneous multiwavelength observations. An example is the data collected on HU Aqr in Sep–Oct 1996, which is shown in Fig. 5. These observations were obtained from space with ROSAT, EUVE and HST and from ground with the AIP 70cm telescope (white light optical photometry) and with the WIRO (Univ. Wyoming 2.3m IR telescope).

The structure of ROSAT and EUVE light curves of HU Aqr have been discussed above. Here we emphasize one further point, the size of the accretion curtain. The HRI onboard ROSAT and the EUVE DS/S are sensitive mainly to the same radiation component: the soft quasi-blackbody component from the accretion spot. Both probe this component at somewhat different energies, with the EUV range being much more sensitive to photo-absorbing cold matter. This is the reason that the dip ingress occurs much earlier in phase in the EUV than in the soft X-ray range. Although the individual instruments do not possess energy resolving power, their combined scans of the dip ingress help to constrain the density profile of the accretion curtain. Appropriate modelling is in progress.

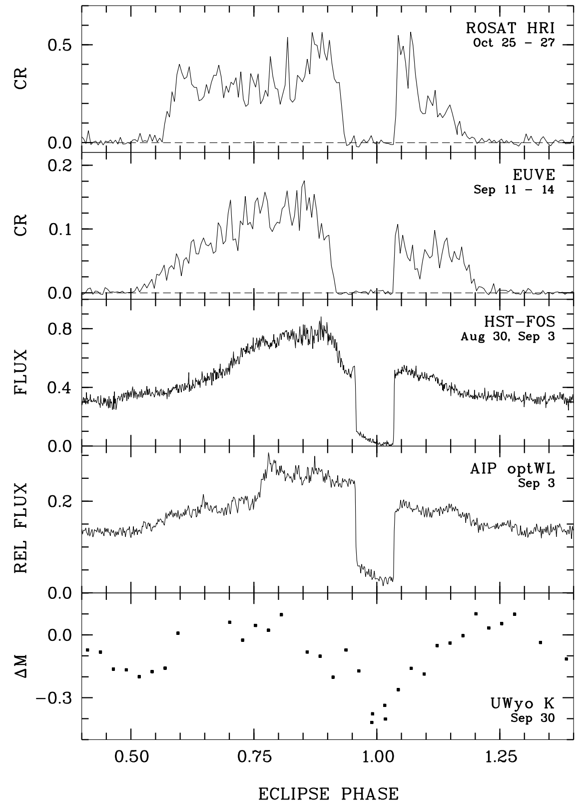

Figure 5. Phase-folded light curves of HU Aqr obtained in different wavelength bands during a coordinated campaign in autumn 1996. The instruments and/or wavelength bands are indicated in the individual panels.

In the third panel of Fig. 5 the mean flux in the 1200-2500 Å range is shown as seen by the HST-FOS. The ultraviolet is dominated by emission from the white dwarf (at all phases outside eclipse), the heated photosphere in and around the accretion region (bright phase), and the accretion stream. The latter is visible at all phases, but in particular during the first half of the eclipse. An absorption dip is present in the UV too, it is not seen in the optical, contrary to the high state where a pronounced dip was seen in UBVRI light curves centered at phase 0.88 (Schwope et al. 1997). Temperatures of the white dwarf and the warm UV-spot were tentatively determined from the faint-phase and bright-minus-faint-phase spectra, and found to be $T_{\rm wd} \sim 10000$ K and $T_{\rm spot} \sim 35000$ K. The smooth rise and fall of the UV flux to and from maximum flux can be modelled with a flat spot on the surface on the white dwarf (approximate location at co-latitude 27°). The light curves at higher energies, which are thought to originate from small regions embedded in the UV-spot, show a much steeper rise and fall which is not compatible with a flat spot and leads to the conclusion that some vertical extent of the emission region is necessary.

The bright phase in the optical is dominated by cyclotron radiation from a ~10 keV plasma. Again, contrary to the high state, the optical light curve is single-humped only (see Schwope 1995 for a comparison of high- and low-state

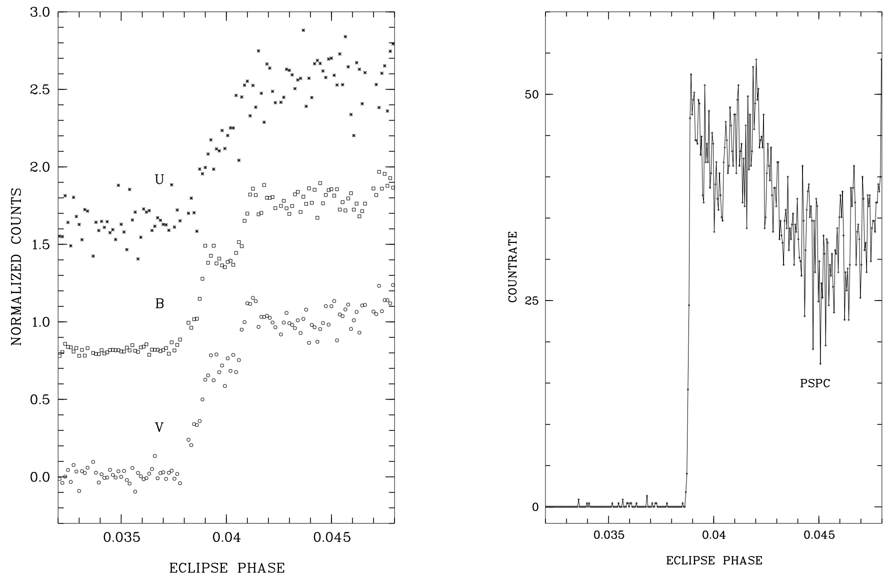

Figure 6. Phase-folded eclipse light curves of HU Aqr centered on egress phase obtained in August 1993 (optical UBV, left) and October/November 1993 (ROSAT, right). The X-ray observations were affected by the wire meshes of the PSPC detector, hence, possible substructure might be instrumental.

light curves). This suggests a much more structured emission region present in the low state than the relatively simple (in terms of cyclotron beaming) and repeatable variation of optical flux suggested for the high state.

Finally, the IR reveals the secondary star by its ellipsoidal light curve. This causes two humps separated by 0.5 in phase. However, the eclipse is still present at IR wavelengths which indicates the IR-tail of the cyclotron component from the accretion spot (for details of the IR-data see the Ciardi et al. (1997)).

Information about the sizes and other parameters of the different emission components can be extracted from eclipse light curves. We show in Fig. 6 two data sets obtained 2.5 months apart with high time resolution in the optical and in the X-ray range. The phase interval covered by Fig. 6 corresponds to two minutes and covers the egress of the white dwarf (plus hot spot) completely. The egress of the accretion stream is complete only after phase 0.1, hence, it is not included in Fig. 6. The data shown here for HU Aqr can be compared with those of its twin, UZ For (see e.g. Bailey & Cropper 1991 for optical data, Stockman & Schmidt 1996 for UV data and Watson 1993 for optical/X-ray data). As in UZ For, the X-ray spot is small, egress takes only about 1 sec. The X-ray egress seems to be essentially simultaneous with the fastest part of the optical egress. A deconvolution of the optical light curve is difficult, at least four components have to be taken into account: the white dwarf, the spot on it (most prominent in the UV), cyclotron radiation and the accretion stream. Particularly intriguing

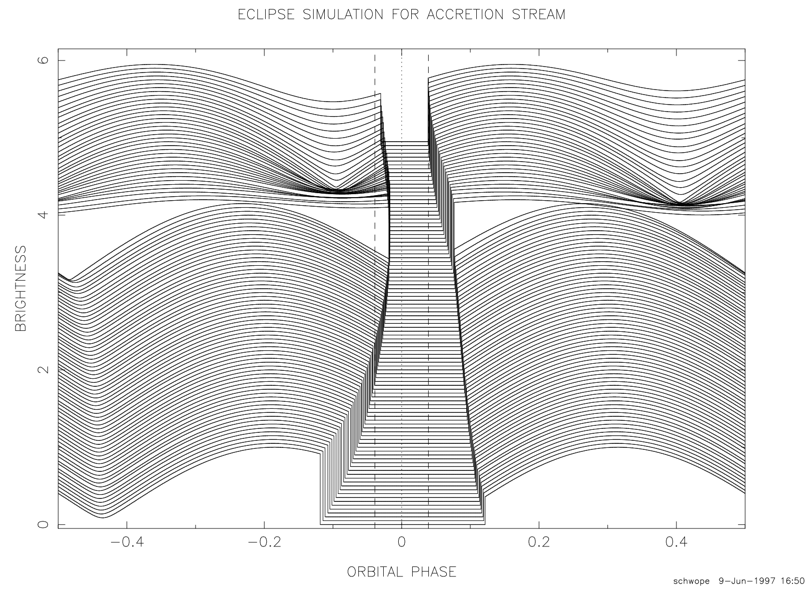

Figure 7. Simulated light curves of stream elements along the one-particle trajectory shown in Fig. 3 (upper panel) in the optically thick approximation. Vertical dashed lines indicate the observed eclipse width and eclipse center of HU Aqr. Constant arbitrary temperature has been assumed along the stream. The light curves of individual elements have been plotted with a small vertical offset with respect to each other, starting with the element nearest to L_1 at bottom. The jump in intensity at element ∼55 occurs when the stream becomes aligned with the magnetic field (coupling region) and the projection angle changes over a short distance.

is the standstill (or even decrease) of optical flux between $\phi = 0.039$ and 0.0405, which is prominent in B and V, but not in U.

The brightness distribution along the accretion stream in HU Aqr has been mapped by Hakala (1995) using low-state eclipse data and applying a MEM-code combined with genetic optimisation. We have started trying a supplementary approach by synthesizing light curves (and trailed spectrograms) for an assumed geometry of the stream. The stream is divided in typically 100 elements, optically thick emission is assumed and, for the first generation models, constant temperature along the stream. Individual elements contribute to the total signal depending on the foreshortening angle and visibility. An example of such a calculation is shown in Fig. 7. Stream parameters were chosen in order to match the likely situation in HU Aqr in its high state. This example shows, that the length of eclipse ingress phase is determined by the extent of the horizontal (ballistic) stream, not by the vertical (magnetic) stream. The situation in the low state is presently unsolved. The sum of the contributions of all stream elements shown in Fig. 7 results in a double-humped light curve with equal maximum height occuring at phases ∼0.25 and ∼0.75, similarly to what is observed in the 1993 high state (Schwope et al. 1997 show high-resolution light curves of the main emission lines). The observations show in addition, that the stream is brighter on its illuminated concave side. The amount of this brightness contrast depends on the line concerned. It is higher for the optically thicker Balmer lines, lower in the (still optically thick) line of ionized Helium He II λ4686.

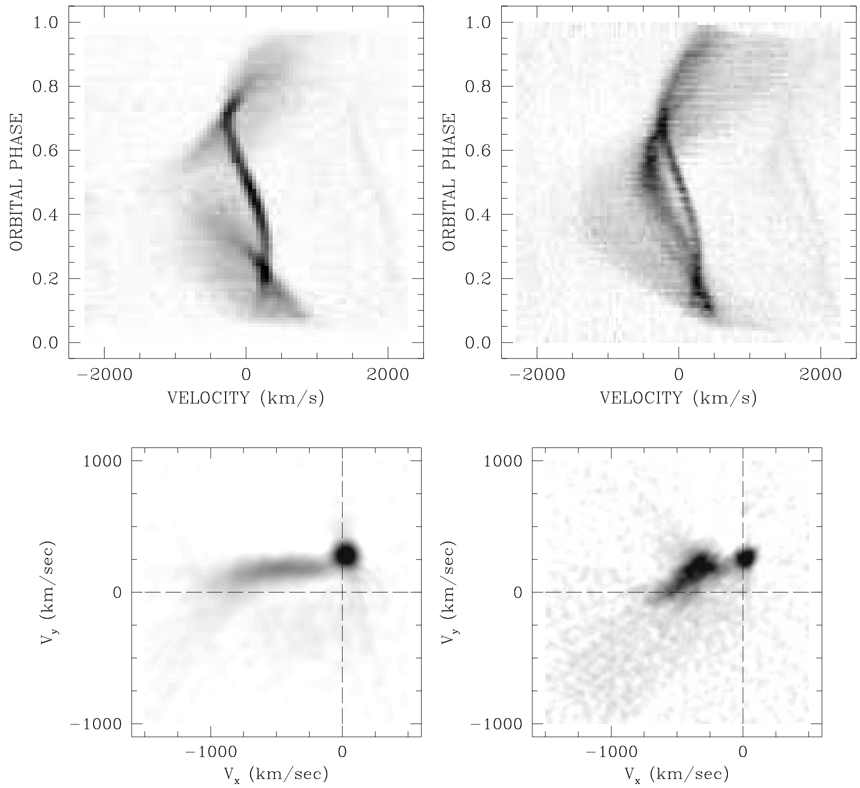

Figure 8. Trailed spectrograms of the HeII 4686 emission line of HU Aqr obtained in a high state (1993, left) and a state of reduced accretion (1996, right). The trailed spectra are continuum-subtracted. In the lower panels the Doppler maps of the trailed spectrograms are shown computed by filtered backprojection.

5. Doppler imaging of HU Aqr - uncovering the stream

In recent years the availability of low-noise CCDs with sufficient high quantum efficiency allowing high-time resolution spectroscopy of even short-period CVs (phase resolution better than 0.05 required) opened a new window on these systems through detailed studies of their emission lines. When analysed by Doppler mapping (Marsh & Horne 1988), images of the line emission regions in the binary system in velocity space (v_x, v_y) can be constructed. A first such investigation of a polar, VV Pup, was presented by Diaz & Steiner (1994).

We obtained high-resolution spectra with full-phase coverage of HU Aqr at two epochs. The first data set was taken in the 1993 high state, the second in a state of reduced accretion in 1996 (Fig. 8). The effect of the reduced accretion rate on the trailed spectrograms is quite dramatic. A constant feature at both occasions is the sinusoidally varying narrow emission line component (NEL) from the heated face of the companion star. This component is bright in the trails at $\phi = 0.5$, when the frontside of the secondary is best visible. The Doppler image of this component is the bright spot at $(v_x, v_y) \simeq (0, 290)$

km s^{-1}. These spots, however do not appear exactly at $v_x = 0$ km s^{-1}, as they should if illumination and re-radiation would occur homogeneously. The shift towards positive velocities in v_x (towards the trailing edge of the secondary star, right in the Doppler map), indicates that significant shielding of the leading hemisphere takes place (Schwope et al. 1997). This is another observational clue to the presence of an accretion curtain, apart from the reduced flux between the narrow dip and the eclipse in the X-ray light curves.

Two further emission line components are visible in the high-state trailed spectrum, another rather narrow so-called high-velocity component (HVC) crossing the NEL at phases $\phi = 0.22$ and 0.70, and a broad underlying component (BBC). These can be assigned to the two parts of the accretion stream, the ballistic (horizontal) part and the magnetic (vertical) part. The correspondence, however, is not exact. The HVC is not as bright as the BBC in the trailed spectrogram, but in the map the horizontal stream (upper left quadrant) is much brighter than the vertical stream (lower left quadrant). This results from the somewhat artificial division between HVC and BBC.

Emission from the horizontal stream is expected to be spread over a large wavelength interval at phases $\sim$0.05 and $\sim$0.55, when the stream is most directly moving away from or approaching the observer. The observer then sees the differently accelerated parts of the stream. If the stream is significantly optically thick, intensity minima should occur also at these phases. Vice versa, around quadrature phases the stream passes the observer with essentially no significant radial velocity (apart from the orbital velocity). Consequently, the velocity spread is small, a narrow emission features, the HVC, emerges. If emission is optically thick, this emission line component is also bright, since the observer sees the stream in full elongation with smallest foreshortening.

All these features can clearly be recognized in the trailed spectrogram obtained in the 1993 high state. The Doppler image shows the horizontal stream to be extended down to $(v_x, v_y) \simeq (-1000, 0)$ km s^{-1}. Such high velocities are reached if the coupling region lies sufficiently downstream (marked by '1' in Fig. 3). The X-ray light curves indicate that at reduced accretion rate the coupling region is shifted towards the inner Lagrangian point L_1. Is this evident from the trailed spectrograms and the Doppler images, too?

On the first glance this is perhaps not so evident from the trailed spectrogram alone but the Doppler map shows clearly that the horizontal stream is far from being so elongated as it has been in the high state. It extends to only about $v_x \simeq -500$ km s^{-1}. Relative to the high state, the vertical stream (lower left quadrant) is more intensive, which is (at least partially) due to the fact, that it is more extended.

The trailed spectrogram shows that both the components originating from the stream changed considerably. The BBC is much more easily recognizable at high velocities than in the high state and the HVC lies much closer to the NEL than in the high state. The latter is a direct consequence from the horizontal stream being much less elongated. There is still a clear separation between NEL and HVC between phases 0.3 and 0.6, indicating that the stream at L_1 is fainter than further downstream. The HVC shows some indication for splitting between phases 0.2 – 0.4. The ultimate reason for this behaviour is presently unclear, it might indicate the presence of a second accretion stream.

High-resolution high-speed spectroscopy in addition opens a new dimension for studies of the distribution of matter in the magnetosphere since it allows to establish eclipse light curves in velocity bins (and eclipse mapping in velocity bins). Such studies have so far never been tried in polars, data as those presented here might open the door to the field.

6. Doppler imaging of QQ Vul - uncovering half stars

The trailed spectrograms of HU Aqr (and those of most AM Herculis stars) clearly display a narrow emission line component which is attributed to the secondary star. A lot of valuable information about the binary system and the stellar components can be extracted from observations of the NEL using its repeatability, its radial velocity, its width (including variability), and intensity (including variability) to derive, e.g., the orbital period, the stellar masses, the size of the secondary star, and the power of the illuminating X-ray source. All but the first point mentioned require a good estimate of the effects of illumination on the secondary. We have already seen, that illumination/re-radiation is (or might be) far from what a numerical model would usually assume, namely symmetry with respect to the line joining both star. It is thus important, to get additional complementary information about the non-illuminated part of the secondary star and to combine both aspects.

In Fig. 9 an example is shown where quasi-chromospheric reprocessed emission lines and photospheric absorption lines has been recorded simultaneously in one system, QQ Vulpeculae. The blue trailed spectrogram shows essentially the same components as seen above for the case of HU Aqr. Here we emphasize the occurence of the bright NEL originating from the secondary star. Line emission from the stream can not be traced very well in the Doppler map due to the rather coarse phase resolution of this data set ($\Delta\phi \simeq 0.05$). The NEL is visible for about 60% of the orbital cycle and has a radial velocity amplitude of $\sim$120 km s^{-1}.

The photospheric NaI-doublet at 8183/8194Å is visible at complementary phases to that of HeII 4686 and possesses a higher radial velocity amplitude of $\sim$265 km s^{-1}. The Doppler images of both lines show a distinct separation between emission and absorption features. Emission was of course not expected from the non-illuminated backside of the secondary star but it was not clear at all that absorption is suppressed so radically from the frontside. A similar effect, perhaps not as pronounced as in QQ Vul, has been seen in AM Her by Southwell et al. (1995) and used to map the NaI surface distribution by Davey & Smith (1996). These two examples demonstrate that care must be taken when using observed radial velocity amplitudes in terms of *bona fide* uniformly distributed photospheric absorption lines in order to estimate stellar masses of polars. The effect of illumination on the photospheric structure and its relation to mass transfer (and mass transfer variations on short timescales) is an unexplored field.

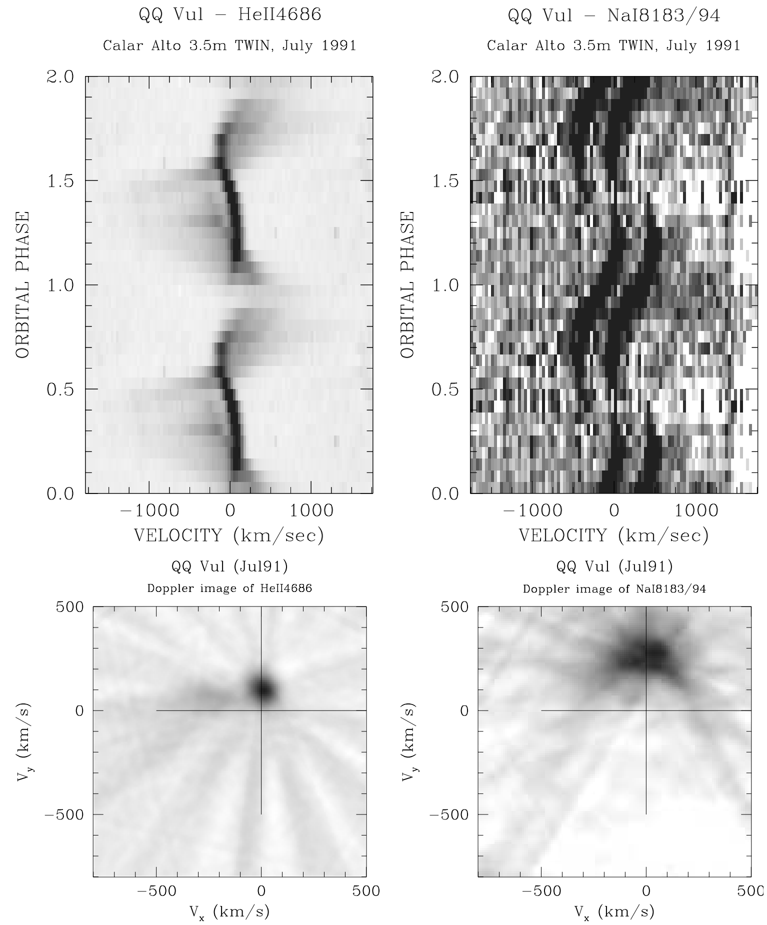

Figure 9. Trailed spectrograms of the HeII 4686 emission and the NaI 8183/94 absorption lines of QQ Vul obtained simultaneously in a 1991 high state. The spetra were continuum-subtracted for representation in the figure. The Doppler maps below show emission from the illuminated front-side and absorption mainly from the non-illuminated back side of the secondary star.

7. Summary and outlook

Using some selected systems we have demonstrated how multi-epoch, multi-wavelength observations have allowed new and detailed insights into the accretion phenomena in AM Herculis stars. In the foreseeable future mapping of even smaller substructures will become possible. XMM will probably allow to measure the sizes of hard and soft X-ray emissions separately, 8m-class optical telescopes will help to explore the accretion stream in the magnetosphere in even greater detail by constructing eclipse maps in velocity bins.

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